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United States Department of Interior
Cincinnati, Ohio

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Edward L. Berg
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Adsorption on powdered activated carbon has been proven to be a feasible method for removing the bulk of the dissolved organic materials from a municipal secondary effluent. The cost of the carbon is such that it must be regenerated and reused. A transport reactor and a fluidized-bed regeneration furnace were evaluated at the Federal Water Quality Administration's pilot plant at Lebanon, Ohio, regenerating carbon from a 10-gal./min. adsorption system. The carbon was regenerated to near virgin capacity by both furnaces. Physical losses in both systems were near 15%. Operating difficulties with the transport reactor furnace led to the selection of the fluidized-bed furnace for further development.

Removal of suspended and soluble organics from wastewater is necessary for industrial and municipal reuse of municipal secondary effluent. The activated sludge process is known to achieve a relatively high degree of organic removal; however, the remaining organics can cause proble of color, odor, and turbidity, and can be a major hindrance to reliable sewage chlorination. Each of these factors can be detrimental to the attainment of the water quality required for industrial, recreational, and domestic uses.

Adsorption of organics on powdered activated carbon followed by sedimentation (powdered carbon adsorption system—PCAS) is one possible method for achieving better removal of organics from secondary effluent. However, the economics of the process are highly dependent upon the cost of powdered carbon. Development of an economical method of carbon regeneration would greatly reduce the cost of this process.

Preliminary bench-scale studies by two FWQA contractors (*1*, *2*) indicated that powdered carbon could be thermally regenerated with carbon losses of less than 10%; the estimated cost was 2.6¢/lb. Based upon laboratory experimental results, each contractor designed and built a pilot-plant size reactor to regenerate spent carbon from the PCAS located at FWQA's Lebanon, Ohio, pilot plant. The object of the work herein was to evaluate the technical feasibility of each thermal reactor, feasibility being determined by adsorption efficiency and carbon loss upon regeneration, and to determine the economics of a powdered carbon adsorption process that includes carbon regeneration.

U. S. Department of Interior, Cincinnati, Ohio.

EXPERIMENTAL PROCEDURE

The technical evaluation of each reactor consisted of continuously contacting virgin carbon (Aqua Nuchar A, West Virginia Pulp and Paper Company) with secondary effluent in a PCAS, concentrating the spent carbon in a thickener, regenerating the spent carbon, and again reusing the carbon in the PCAS. The amount of organic materials removed by the PCAS reflects adsorption efficiency. Adsorption efficiency and loss of powdered carbon upon regeneration determine technical feasibility.

EXPERIMENTAL EQUIPMENT

Figure 1 is a schematic diagram of the PCAS. This system, which treats secondary effluent at 10 gal./min., is a two-stage countercurrent mixer-settler and filtration operation, previously

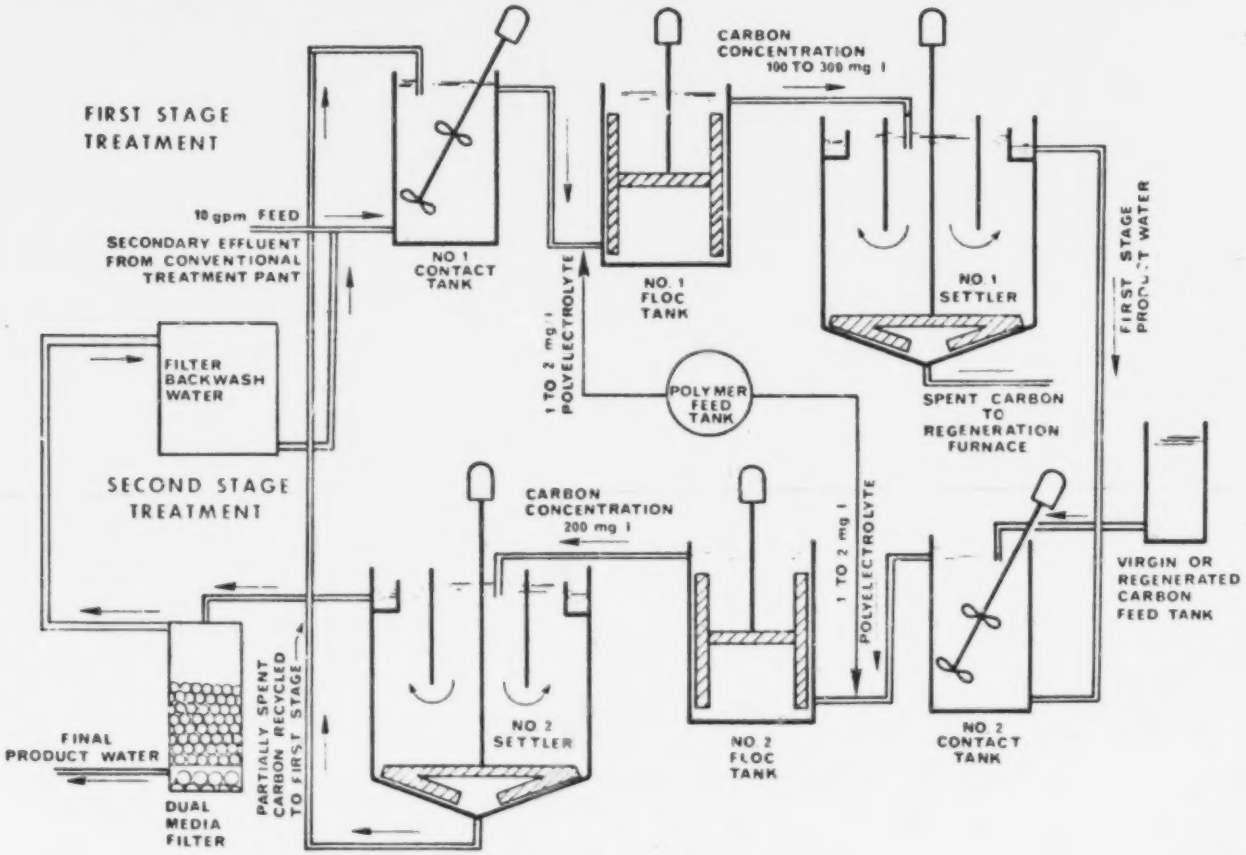
FIRST STAGE TREATMENT
10 gpm FEED
SECONDARY EFFLUENT FROM CONVENTIONAL TREATMENT PANT
NO 1 CONTACT TANK
NO 1 FLOC TANK
CARBON CONCENTRATION 100 TO 300 mg l
NO 1 SETTLER
FIRST STAGE PRODUCT WATER
1 TO 2 mg l POLYELECTROLYTE
POLYMER FEED TANK
SPENT CARBON TO REGENERATION FURNACE
FILTER BACKWASH WATER
SECOND STAGE TREATMENT
CARBON CONCENTRATION 200 mg l
1 TO 2 mg l POLYELECTROLYTE
VIRGIN OR REGENERATED CARBON FEED TANK
NO 2 SETTLER
NO 2 FLOC TANK
NO 2 CONTACT TANK
FINAL PRODUCT WATER
DUAL MEDIA FILTER
PARTIALLY SPENT CARBON RECYCLED TO FIRST STAGE

Fig. 1. Powdered carbon adsorption system.

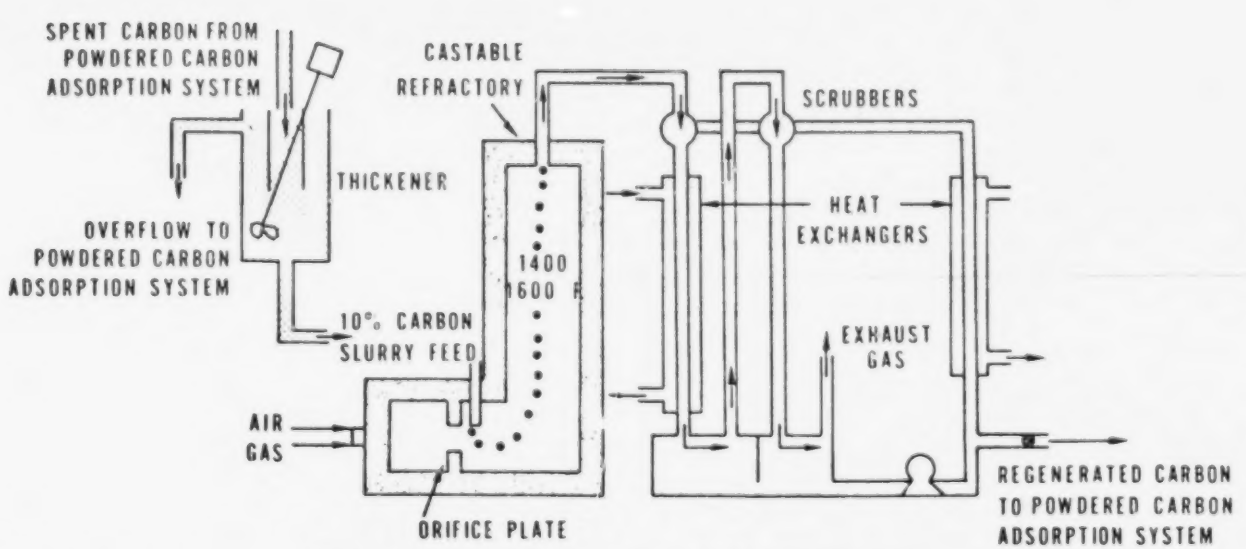

Fig. 2. Powdered carbon regeneration system; transport reactor.

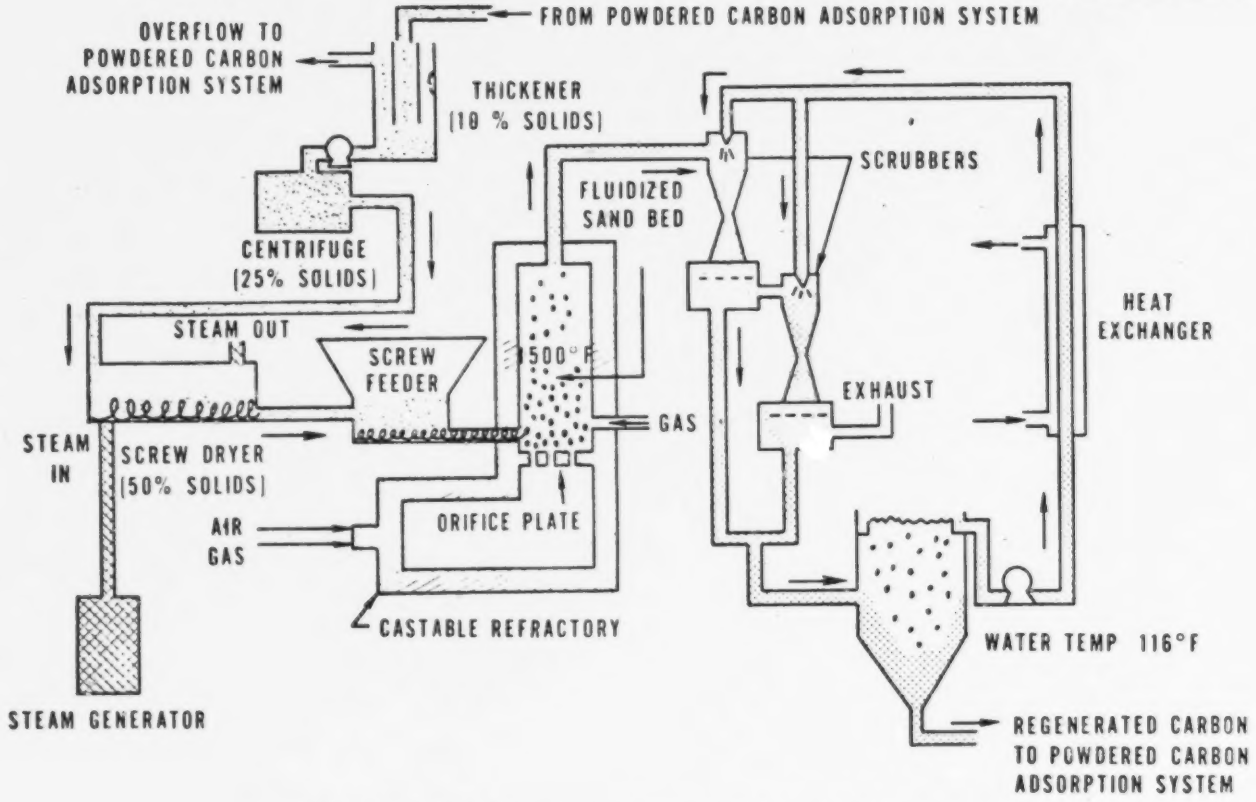

Fig. 3. Powdered carbon regeneration system; fluidized-bed reactor.

described in detail by Davies (3) and Masse (4). A cationic polyelectrolyte coagulates the fine carbon particles and enhances sedimentation.

The wastewater supplied to the PCAS originated from two sources: secondary effluent from a 15-gal./min. pilot-plant activated sludge process treating domestic wastewater, and product water from a single-stage lime clarification system (LCS) previously described by Berg (5); each system treats the primary effluent from Lebanon, Ohio.

Figure 2 shows the regeneration process incorporating the transport reactor. The reactor designed capacity is 40 lb./hr. of a spent powdered carbon slurry that contains 10% solids; the carbon particle has about a 1-sec. residence time at a gas temperature of 1,400° to 1,500°F. The reactor is described in detail by Bloom, Joseph, Friedman, and Hopkins (6).

Figure 3 shows the regeneration process incorporating the fluidized-bed reactor. The reactor designed capacity is 7.5 lb./hr. of spent carbon containing 50% solids. A fluidized bed of coarse inert sand at 1,400°F. serves as a controlled constant-temperature zone for regeneration, fluidization occurring by the action of hot combustion gases passing through a distribution plate containing $\frac{1}{8}$-in. diam. holes. A Vibra-Screw feeder conveys spent powdered carbon into the fluidized bed.

Sampling of the PCAS, when used with the transport reactor, consisted of taking influent and effluent grab samples every 2 hr. for turbidity measurement (Jackson turbidity units—JTU) and every 4 hr. for total organic carbon measurements (TOC) (measured with a Beckman Carbonaceous Analyzer) per 24-hr. day. Sampling of the PCAS, when used with the fluidized-bed reactor, was somewhat different in that a different turbidimeter* measured influent and effluent turbidity, and turbidity and TOC sample collection was over a 16-hr. period of each day. Sampling of the reactors consisted of collecting spent and regenerated carbon samples, the sample solids undergoing laboratory analysis for volatiles, fixed carbon, and ash content. The analytical procedure consisted of drying the sample at 106°C. for 24 hr. to determine solids-moisture content, heating the remaining sample to 400°C. for 2 hr. to obtain volatile content, and finally oxidizing all carbon at 800°C. until constant weight to determine ash content. The weight of volatiles plus ash subtracted from the initial dried weight represents the fixed carbon.

EXPERIMENTAL RESULTS

TRANSPORT REACTOR STUDY

The study in which the transport reactor regenerated spent powdered carbon from the PCAS covered a period of 41 days, 34 of which were continuous operation. The PCAS received secondary effluent for 39 days and lime clarified primary effluent the remaining two days. Daily averages of TOC and turbidity, using virgin carbon or carbon regenerated at a mean temperature of 1,458°F. during this period, are shown in Figure 4.

*Hach Turbidimeter Models 1860 and 2100 were used during the periods of evaluating the transport- and fluidized-bed reactors, respectively. Turbidities from the two meters differ.

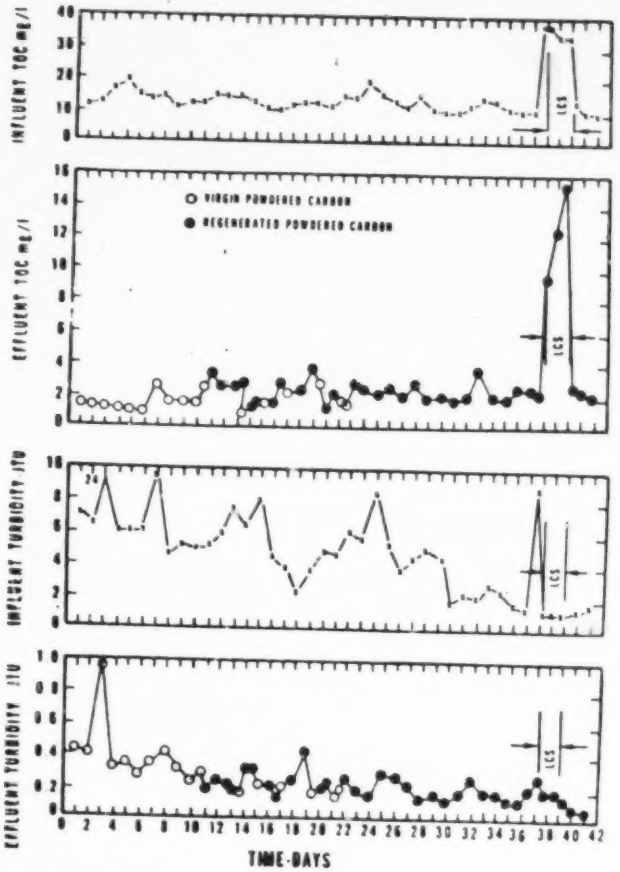

Fig. 4. Turbidity and TOC values using virgin and regenerated carbon during the transport reactor study.

The data in Figure 4 show a daily variation in product TOC values when using either regenerated or virgin carbon in the PCAS. The variation does not appear to be a loss of carbon adsorption capacity upon regeneration, since the use of regenerated carbon followed by virgin carbon, or vice versa, results in product TOC values of nearly the same magnitude. The relatively constant product TOC values between the 22nd and 36th days also indicate little loss of adsorption efficiency upon regeneration. Thus the variation in TOC values results from such factors as analytical error, carbon leakage through the filters, certain inadequacies of the PCAS, or a change in wastewater character. The latter case is perhaps more likely since the influent TOC throughout the study shows a slight cycling effect and the product turbidity appears to parallel closely the product TOC values between the 10th and 34th days of operation. Nevertheless, the average product TOC values, when using virgin and regenerated carbon, were 1.7 and 2.4 mg. liter, respectively, while the influent TOC averaged 13.6 and 13.8 mg. liter for virgin and regenerated carbon, respectively. The omission of the first six days of operation results in an average product TOC of 2.1 mg./liter with virgin carbon; this value compares closely with the average TOC with regenerated carbon. In either case, and based upon the total weight of carbon fed, regeneration results in, at most, a slight loss of adsorption efficiency.

On the 36th day of operation, the PCAS received lime clarified primary effluent because of a breakdown in the activated sludge process. This change resulted in a final effluent averaging 12.1 mg./liter TOC or slightly lower than the average TOC of 15.6 mg./liter in secondary effluent. These results suggest the technical feasibility of the PCAS for serving as a replacement for biological oxidation processes, which are susceptible to frequent upsets because of toxic materials or cold weather.

FLUIDIZED-BED REACTOR STUDY

The study in which the fluidized-bed reactor regenerated spent powdered carbon from the PCAS covered a period of 34 days; the regeneration temperature averaged 1,250°F. During the previous transport reactor study, the PCAS received virgin carbon when regenerated carbon was unavailable to assure continuous operation. However, when regenerated carbon was unavailable during this study, the PCAS was put on standby until it became available. This procedure makes it possible to correlate more closely the number of regeneration cycles with the respective TOC and fixed carbon values. Figure 5 shows the daily averages of the TOC and turbidity values during the fluidized-bed reactor study; Table 1 gives the average TOC values for each of the regeneration cycles.

The influent TOC values in Figure 5 indicate secondary effluent of good quality for the first 15 days of operation. Influent turbidities during this period were high. The low effluent turbidities, however, indicate that much of the turbidity was of a settleable nature and was subsequently removed in the PCAS sedimentation step. During the remainder of the fluidized-bed study, an abnormal amount of biological floc carryover from the activated sludge process contributed to higher influent TOC. Since measurement of TOC was on unfiltered samples, the amount of soluble TOC adsorbed by the carbon and that amount removed by sedimentation of solids was indistinguishable. Therefore an accurate comparison of adsorption efficiency between some of the carbon regeneration cycles is difficult. Nevertheless, Table 1 indicates that initial virgin carbon and first-cycle regenerated carbon remove about the same amount of TOC at comparable influent TOC loadings. Carbon regenerated a second and third time gives comparable effluent TOC values and these values compare favorably with the effluent TOC of virgin carbon used at the end of the study; these regeneration cycles have about the same influent TOC value. The 3.6th regenerated carbon (0.6 of the re-

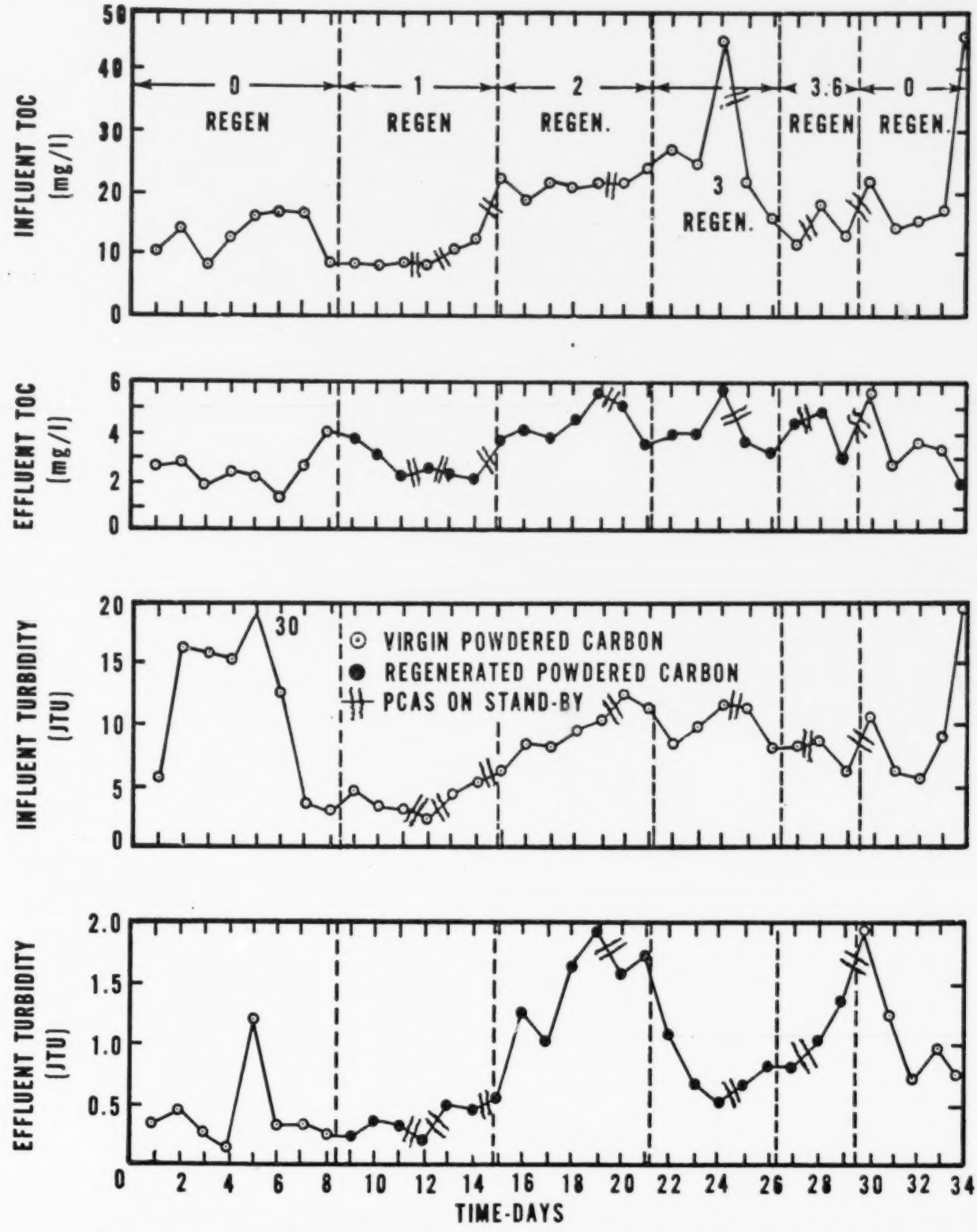

Fig. 5. Turbidity and TOC values for virgin carbon and regenerated carbon from the fluidized-bed reactor.

TABLE 1. AVERAGE TOC VALUES FOR VARIOUS REGENERATION CYCLES

No. of regenerations	Influent TOC, mg./liter	Effluent TOC, mg./liter
0	12.9	2.5
1	9.3	2.7
2	21.7	4.4
3	27.0	4.2
3.6	14.5	3.7
0	23.5	3.6

maining carbon reactivated a fourth time) gives an effluent TOC slightly greater than that of initial virgin carbon at comparable influent TOC. The 3.6th regenerated cycle carbon also gives an effluent TOC about equal to virgin carbon used at the end of the study, but at a lower influent TOC value. Although the inconsistent data in Table 1 make a concise relationship between adsorption efficiency and regeneration cycle difficult, it is evident that the loss of adsorption efficiency upon regeneration is quite small.

LOSS OF ADSORPTION EFFICIENCY UPON REGENERATION

Table 2 summarizes the overall TOC results for the transport- and fluidized-bed reactor studies. Each reactor study indicates that regenerated carbon removes slightly less TOC than virgin carbon at about the same influent TOC loading.

The loss in adsorption efficiency upon regeneration can be attributed to the decrease in fixed carbon available for adsorption as shown in Figure 6. These results from the transport reactor study indicate after regenera-

TABLE 2. AVERAGE INFLUENT AND EFFLUENT TOC FOR THE REACTOR STUDIES

	Influent, mg./liter	Effluent, mg./liter
Transport reactor		
(A) Virgin	13.6	1.7
(B) Regen.	13.8	2.4
Fluidized-bed reactor		
(A) Virgin	18.1	3.1
(B) Regen.	18.1	3.8

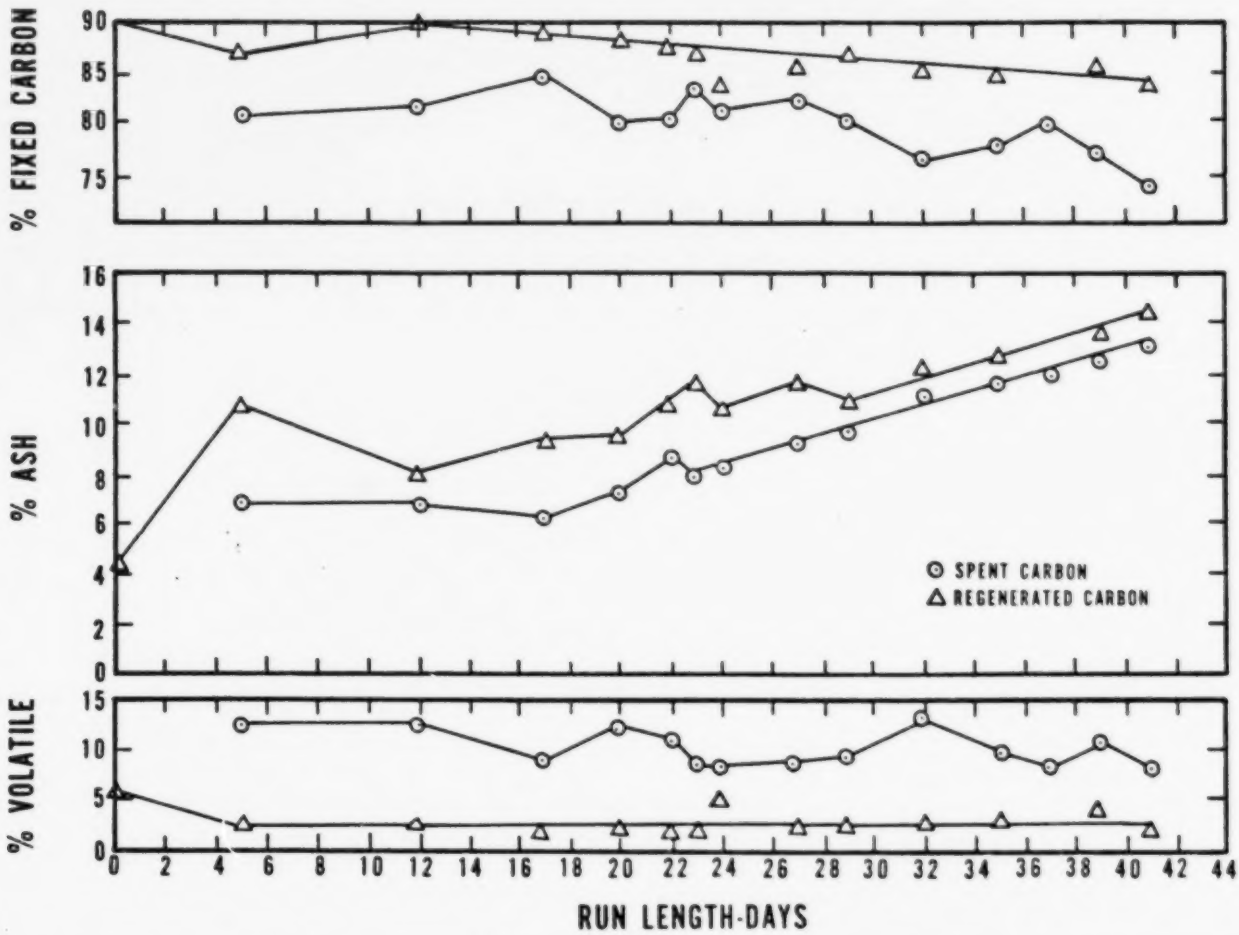

Fig. 6. Proportion of volatiles, ash, and fixed carbon for virgin, spent, and regenerated carbons during the transport reactor study.

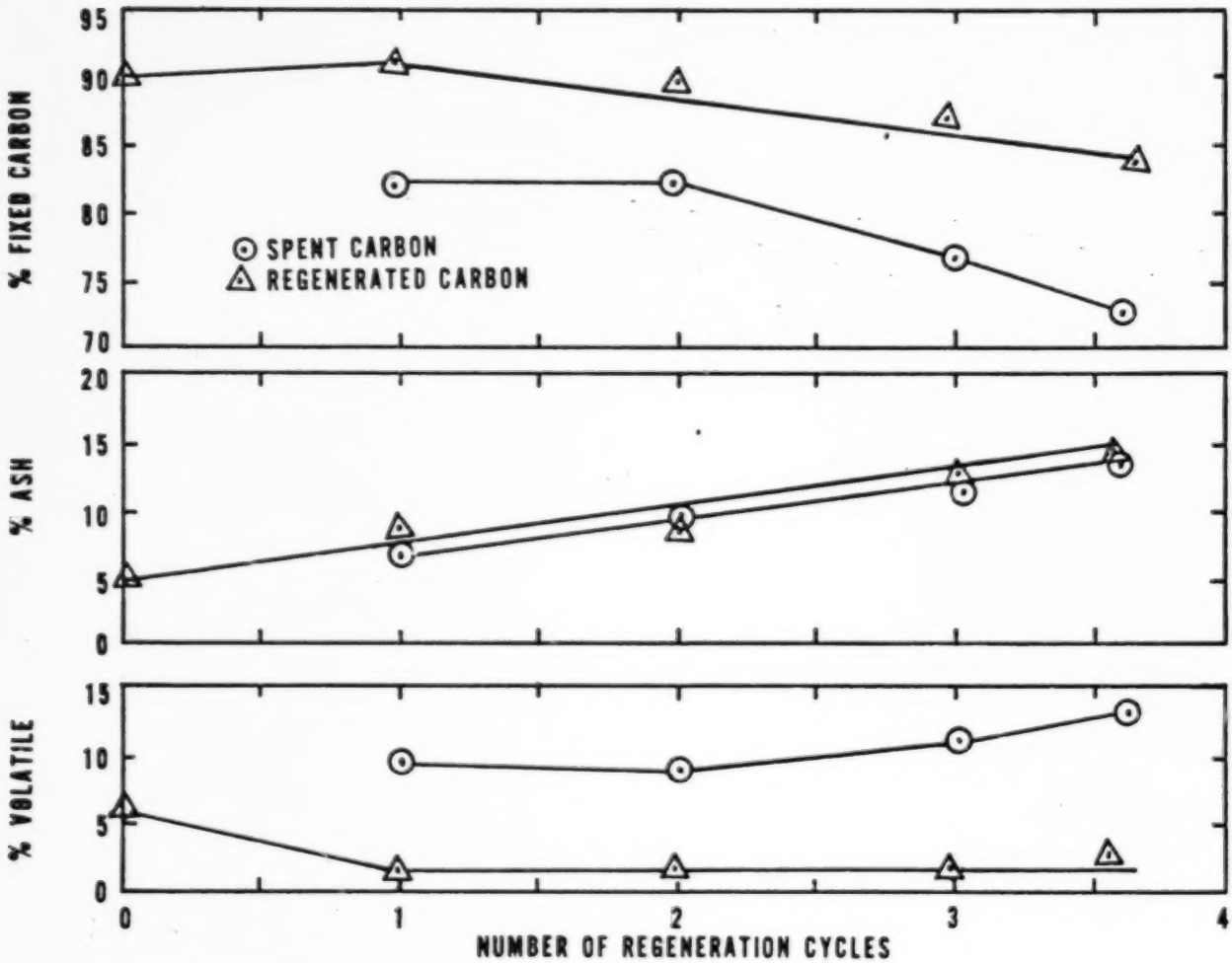

Fig. 7. Proportion of volatiles, ash, and fixed carbon for virgin, spent, and regenerated carbons during the fluidized-bed reactor study.

tion of spent carbon a relatively constant volatile content of 2.5% and a fixed carbon and ash content decreasing and increasing, respectively, at a rate of 0.28% per day. These rates are based upon linear parts of the curves. The rate at which fixed carbon decreases can be expressed as percent of fixed carbon per regeneration cycle; a 7% difference between initial and final fixed carbon content divided by 3.2 regeneration cycles gives a rate of 2.2% per regeneration cycle. For spent carbon the ash content curve has a slope corresponding to the regenerated carbon slope, while the volatile and fixed carbon content varies as would be expected for a variable suspended solid loading to the PCAS.

Results for percentage of fixed carbon, ash, and volatile content for the fluidized-bed reactor study closely resemble those for the transport reactor study as shown in Figure 7. For regenerated carbon fixed carbon decreases at a rate of 1.9% per regeneration cycle, while ash content increases at this same rate. The percent volatiles of regenerated carbon remains relatively constant at 1.5%. For spent carbon, percent fixed carbon and volatiles are inversely related while percent ash increases at a rate equal to that of regenerated carbon. This equality was also apparent during the transport reactor study. It is also significant that regenerated carbon from the fluidized-bed reactor, operating at 1,250°F., contains only 1.5% volatiles as opposed to regenerated carbon containing 2.5% volatiles from the transport reactor operating at 1,395° and 1,521°F. at the top and bottom of the reactor, respectively. Thus it would appear that regeneration of spent carbon in a lower, but uniform temperature zone is more effective in removing volatile organics than at a nonuniform and slightly higher temperature zone.

Decreasing surface area* with increasing ash content also reflects loss of adsorption efficiency as shown in

*Surface area measured by nitrogen adsorption (B.E.T.).

TABLE 3. RECOVERY OF FIXED CARBON UPON REGENERATION BY THREE DISTINCT METHODS

Reactor study	Method I			Method II			Method III
	No. of batches proc.	Ave. % rec.	Range of % rec.	No. of batches proc.	Ave. % rec.	Range of % rec.	Percent recovery
Transport	3	85	82 to 89	14	81	67 to 94	85
Fluidized bed	7	81	69 to 93	20	86	65 to 106	85

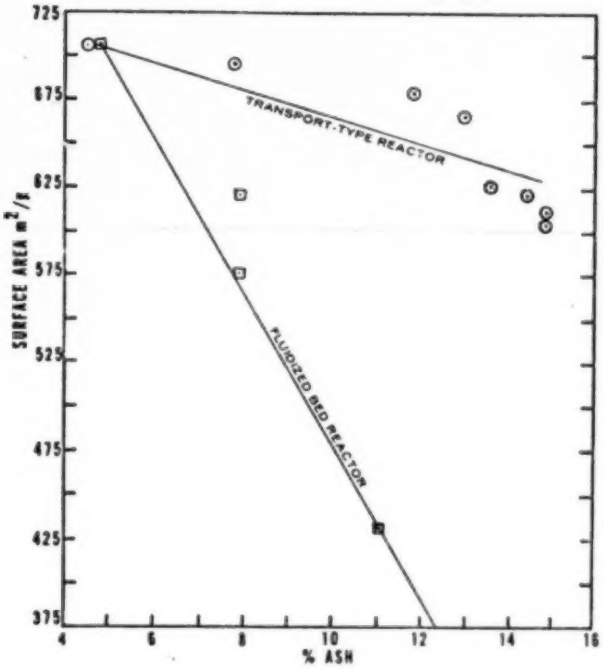

Fig. 8. Surface area of regenerated carbon based upon total weight of sample versus ash content.

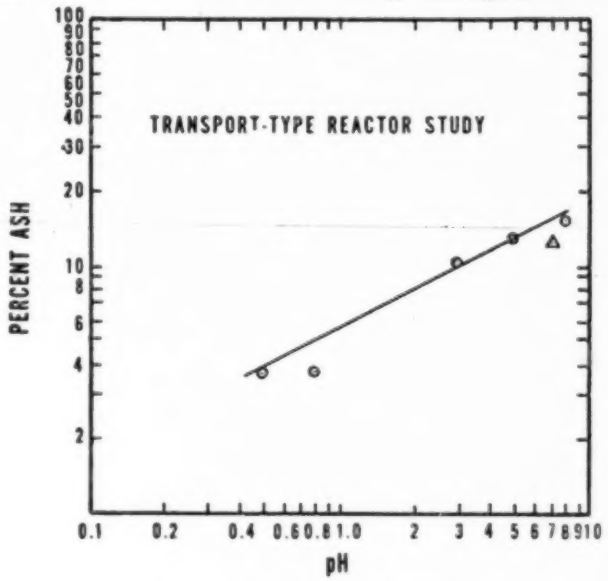

Fig. 9. Ash remaining after washing regenerated carbon with HCl and distilled water.

Figure 8. These results show the surface area of 1 g. of regenerated carbon decreasing at rates of 3.7 and 18.8 sq. m./1% ash for the transport- and fluidized-bed reactor studies, respectively. It should be noted in Figure 8 that the virgin carbon sample surface area (at 4.6% ash) for the two studies agree closely, thereby eliminating analytical error as the reason for the large difference in the two slopes. The longer retention time of carbon at a lower regeneration temperature in the fluidized bed could affect the surface area. Of more importance is the fact that regenerated carbon having a surface area far less than another at the same ash content results in only a slight decrease of adsorption efficiency as indicated previously when comparing final effluent TOC values (Table 2) for the two reactor studies. Thus it is apparent that regeneration closes pores that adsorb nitrogen, but has little effect upon those pores which adsorb organics in secondary effluent. Thus the surface area measurement by nitrogen adsorption does not appear to be a major indicator of adsorption efficiency when treating secondary effluent with powdered carbon.

The ash, assumed to be inorganic salts, is soluble in hydrochloric acid as shown in Figure 9, thereby providing a method for preventing excessive ash buildup in a PCAS.

CARBON LOSSES

The loss of powdered carbon upon regeneration for each reactor study was determined by the following three methods: batch amounts of virgin carbon were regenerated and collected and the percent fixed carbon recovery was determined; the second method was identical to the first except that spent carbon was regenerated; for the third method, the amount of fixed carbon fed to the PCAS and that remaining upon termination of the study was determined. From these data the percent fixed carbon loss per regeneration cycle was calculated.

Table 3 summarizes the fixed carbon recovery for the three methods. The average fixed carbon recovery for the three methods is about 84% for each reactor study. The percent recovery ranges are relatively large, at-

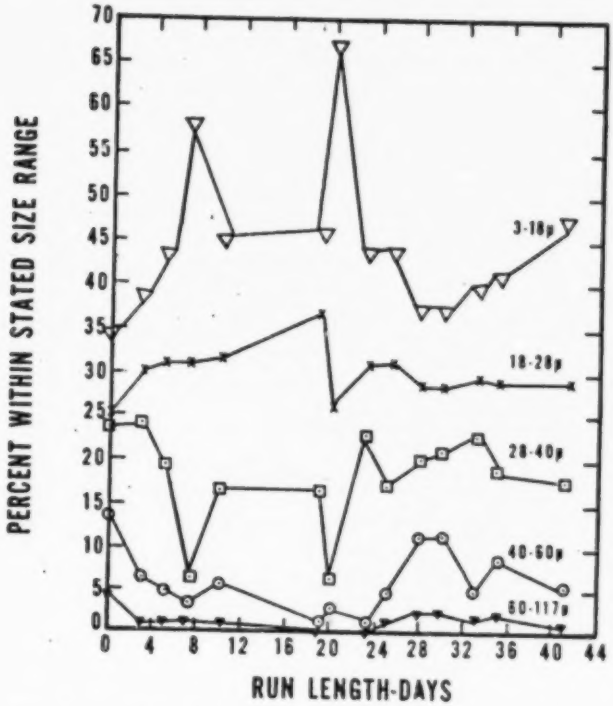

Fig. 10. Particle-size distribution during the transport study.

tributed to carbon holdup in the reactor and wet scrubbing systems or possible analytical error for fixed carbon.

The exact reason for carbon loss is not readily discernible. When operating the transport reactor, metered volumes of propane and air were in stoichiometric quantities for combustion, thereby leaving no excess oxygen, at least theoretically, for combustion of carbon. However, operation of the fluidized-bed reactor consisted of controlling air and propane volumes to maintain, in the exhaust gas, an oxygen content ranging from 0 to 1%; the oxygen content averaged 0.6%.* Since the two reactors gave almost identical recoveries of fixed carbon, it is unlikely that the carbon loss is due to direct carbon combustion. Battelle's work (2) supports this conclusion; they found that regeneration in a bench-scale fluidized-bed reactor with a fluidizing gas containing 2% excess oxygen at 1,000°F. resulted in a carbon loss of less than 2%. The average operating temperature during the fluidized-bed reactor study was 1,253°F.

Carbon loss in the stack gases was also investigated. Tests using porous bags over the exhaust gas stack and use of two additional bench-scale wet scrubbers indicated carbon loss of only about 0.1% during each reactor study.

Carbon particle degradation was also investigated. Figures 10 and 11 show particle-size distribution data

*Oxygen content measured by Paramagnetic Analyzer.

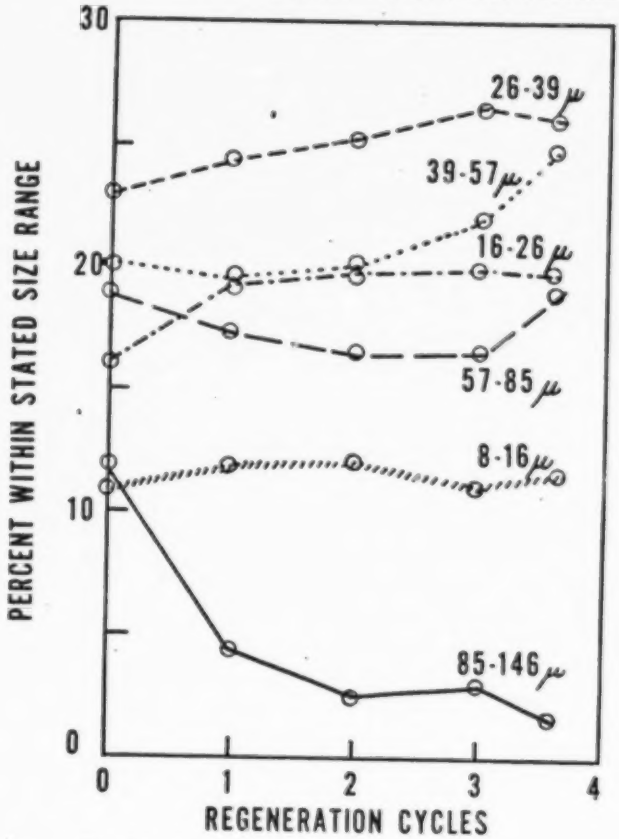

Fig. 11. Particle-size distribution during the fluidized-bed study.

for the transport- and fluidized-bed reactor studies, respectively.

Distribution data in Figure 10 (transport reactor) indicate disintegration of the carbon particle into smaller sizes during the first eight days. This period indicates the greatest reduction of particles to be in the size range 28 to 40 μ, while the 3 to 18 μ size range increases in number of particles. During the period between 8 and 22 days of operation, fluctuations in particle-size distribution occur due to intermittent addition of virgin carbon or to clogging of the small aperture (140 diam.) within the Coulter Counter (Model C). From 22 days on, Figure 10 indicates a large increase in the 3 to 18 μ size range; the major size reduction occurs in the 40 to 60 μ range as opposed to a major reduction in the 28 to 40 μ range during the first eight days. Thus these results suggest that the carbon particle continuously disintegrates to undetectable sizes in the exhaust gas which accounts, at least in part, for carbon loss. However, particle-size distribution data for the fluidized-bed reactor study do not fully support the disintegration theory. As shown in Figure 11, the number of particles within any size range, excluding the 85 to 146 μ range, remains relatively constant. Three possible explana-

tions offered for the difference in results from the two reactor studies are: (1) lower operating temperature of the fluidized-bed reactor, (2) a constant-temperature zone produced by the bed (no hot spots), and (3) during the fluidized-bed reactor study, the Coulter Counter contained an aperture diameter of 280 μ, twice the size used in the instrument during the transport reactor study. Thus the inability of the large aperture instrument to measure a significant amount of particles having diameters less than 8 μ adversely affects the sensitivity of the data.

REGENERATION PERFORMANCE

TRANSPORT REACTOR

The major operating problem experienced with the transport reactor was the maintenance of a choke ring (orifice in Figure 2) located at the end of the propane-air burner assembly. The primary purpose of the choke ring is to produce a high-velocity gas stream and turbulent action at the point of spent carbon slurry injection. This design minimizes carbon retention time inside the reactor and prevents carbon from clogging safety devices located in front of the burner assembly. Initially, regeneration of virgin carbon resulted in total carbon recoveries averaging 72.5% for seven runs. Inspection inside the reactor showed only fragmentary evidence of a choke ring. Subsequent replacement of the choke ring, constructed of porous firebrick, resulted in 82.5% of the total carbon weight recovered for five more runs with virgin carbon. Comparison of recovery results before and after installation of the choke ring indicate that excessive retention time in the combustion zone adversely affects carbon recovery efficiency. During the last of the five previous runs, part of the choke ring became deformed. Subsequent repair with high-temperature cement and three more runs with virgin carbon resulted in an average total carbon recovery of 85%. This choke ring again became badly deformed; a final replacement was a high alumina content choke ring (Massilon Refractories, Inc., Massilon, Ohio) designed to operate at temperatures up to 3,250°F. After installing this choke ring the transport reactor study began; the choke ring persisted until the 35th day of operation and slowly deteriorated until the last two regeneration runs when severe deformation occurred. The exact cause for the choke ring deformation is unknown but possible causes are misalignment of the propane-air flame or the chemical reaction of alumina with silicates or some other contaminant in the water.

FLUIDIZED-BED REACTOR

The fluidized-bed reactor was originally designed to process 8 lb./hr. of spent powdered carbon containing 50% solids. Early investigation indicated solid-bowl centrifuging would dewater spent carbon to about 25% solids. A Holo-Flite screw dryer, after three passes, further dewatered the spent carbon to 50% solids. A vibra-screw feeder attempted to convey the 50% solids into the reactor, however, the feeder proved ineffective due to rat-holing characteristics and solids drying within the hot screw. Further tests indicated that the feeder would effectively convey 25% solids into the reactor. The Holo-Flite drying process was then by-passed during the fluidized-bed reactor study. The adverse effects of a 25 versus 50% solids feed were lower feed rate of about 4 (dry) lb./hr., a lower operating temperature of 1,253°F., and sand from the fluidized bed carried out of the reactor and into the scrubber system.

COST OF PCAS

An economic analysis of the fluidized-bed reactor is still pending, thus the ensuing carbon regeneration cost estimate is based upon reported cost data for the transport reactor.

The estimated cost of regenerating spent powdered carbon is 2.6¢/lb. (*1*) but approximates 3¢/lb. if waste heat is not utilized. A 10% slurry feed and 95% recovery of carbon were the basis for the cost estimates. However, the two reactor studies reported herein indicate about 85% recovery which only increases the regeneration cost to 2.86¢/lb. Lower carbon recovery, however, is more fully realized in the cost of makeup carbon to the PCAS, which is about 2.1 and 0.7¢/1,000 gal. of water treated at 85 and 95% carbon recovery, respectively. Combining the two costs, regeneration and carbon makeup, results in 6.2 and 4.8¢/1,000 gal. of water treated, a difference of 1.4¢/1,000 gal. in the two recoveries. Virgin carbon costing 8.5¢/lb. and use of 200 mg./liter of carbon in the PCAS were the basis for these calculations.

Bloom (*5*) pointed out that large cost savings were possible if the slurry feed was concentrated from 10 to 15% solids. The fluidized-bed reactor study indicated

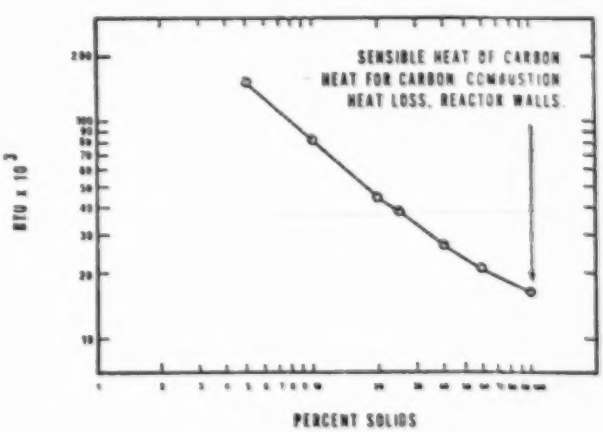

Fig. 12. Number of B.t.u. to raise various concentrations of carbon slurries (basis 4 lb. carton) to 1,600°F.

TABLE 4. CHEMICAL COST OF 10-MILLION GAL./DAY PLANT

	85% rec.	95% rec.
Carbon regeneration with centrifugation and heat utilization	2.3	2.4
Makeup carbon (200 p.p.m. at 8.5¢/lb.)	2.1	0.7
Polyelectrolyte (1 p.p.m. in each stage of PCAS treating secondary effluent)	2.0	2.0
Total chemical cost (cents per 1,000 gal.)	6.4	5.1

TABLE 5. OPERATING COST OF A 10-MILLION GAL./DAY PCAS

	Annual operating cost
1. Capital cost ($703,000 for 20 years at 6%)	$61,300
2. Maintenance (3% of equipment and 1% of structures)	12,150
3. Labor	66,600
4. Power (1¢/kw. hr.)	21,400
Total operating cost or 4.5¢/1,000 gal.	$161,450

that centrifugation concentrates spent carbon to 25% solids; the estimated cost being 0.2¢/lb. (dry) for a 10 million gal./day PCAS (7). From Figure 12 the B.t.u. ratio of 10% solids: 25% solids is about 88,000 : 44,000 or 2 : 1. Thus for the same capital expenditures, etc., twice as much carbon can be processed in the reactor which reduces the regeneration cost to 1.4¢/lb. The lower regeneration cost reduces the overall chemical cost of a 10 million gal./day PCAS by 22%; Table 4 itemizes the chemical cost.

Table 5 shows the estimated cost of a PCAS using two accelerators and a four-cell gravity sand filter operating at a filtration rate of 3 gal./(min.)(sq. ft.); the net cost is about 4.5¢/1,000 gal. of water treated for a 10-million gal./day plant. Thus the total estimated cost of a PCAS with regeneration of spent carbon is about 11¢/1,000 gal. when treating a good quality secondary effluent.

CONCLUSIONS

A two-stage powdered carbon adsorption system utilized thermally regenerated carbon from a transport reactor and from a fluidized-bed reactor to adsorb organics in secondary effluent. Each reactor regenerated spent carbon capable of removing about 80% of the total organics in secondary effluent; the PCAS effluent TOC values averaged 2 to 4 mg./liter for 3.2 to 3.6 regeneration cycles.

The regeneration of spent carbon results in a carbon sample containing 1 to 3% volatiles, an ash content which increases upon regeneration with a corresponding decrease in fixed carbon content at rates of 1.9 to 2.2% per regeneration cycle.

Carbon adsorption efficiency decreased slightly upon regeneration; the steady decrease in fixed carbon available for adsorbing organics accounts for the slight loss.

During each reactor study the surface area of regenerated carbon decreased with increasing ash content. The rate of decrease was much greater for the fluidized-bed reactor, which may have resulted from longer carbon retention time in the fluidized bed. Because regenerated carbon from both reactors adsorbed about the same organics with different surface areas, the nitrogen adsorption measurement does not truly reflect loss of adsorption efficiency.

The recovery of fixed carbon for each of the reactors was about 85%. The exact reason for the loss was undetermined.

The performance of the transport reactor is highly dependent upon a choke ring which has a relatively short life. Until this design feature is overcome, the excessive loss of carbon prevents this regeneration method from competing with the fluidized-bed reactor which performed without any major difficulty.

An economic analysis for a 10-million gal./day PCAS that includes regeneration, heat utilization, and centrifugation indicates a total cost of 11¢/1,000 gal. of water treated.

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LITERATURE CITED

1. *FWPCA Contract No. 14-12-92*, FMC Corp.
2. *FWPCA Contract No. 14-12-113*, Battelle Memorial Inst.
3. Davies, D. S., and R. A. Kaplan, *Chem. Eng. Progr.*, 60(12), 46–50 (1964).
4. Masse, A. N., paper presented at 156th Natl. Am. Chem. Soc. Meeting, Atlantic City, N. J. (Sept. 8–13, 1968).
5. Berg, E. L., *Water Wastes Eng.*, 7(3), 42–46 (1970).
6. Bloom, R., R. T. Joseph, L. D. Friedman, and C. B. Hopkins, *Environmental Sci. Technol.*, 214–217 (Mar. 1969).
7. *FWPCA Contract No. 14-12-59*, Dorr-Oliver Co.
8. *FWPCA Contract No. 14-12-400*, (GATX), Infilco Products Co.